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Ice Jam Response and Mitigation: The Need for Cooperative Succession Planning and Knowledge Transfer

K. D. White
U.S. Army ERDC Cold Regions Research and Engineering Laboratory, Hanover, NH 03755
Kathleen.D.White@usace.army.mil
F.E. Hicks
Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2W2
Faye.Hicks@ualberta.ca
S. Beltaos
Environment Canada, National Water Research Institute, Burlington, Ontario, Canada L7R 4A6
Spyros.Beltaos@ec.gc.ca
G. Loss
National Weather Service - Western Region, Great Falls, MT 59404-4933
Gina.Loss@noaa.gov

The international community of engineers and scientists involved with river ice hydraulics, exemplified by those participating in the activities of the Committee on River Ice Processes and the Environment, is relatively small and collegial. The many years of experience represented by those gathering for the workshops is both a strength and a reminder that the river ice community is aging. This is particularly true in the smaller group dedicated to emergency response to ice jams and the design of ice mitigation measures. For example, in 1990, the US Army Cold Regions Research and Engineering Laboratory (CRREL) had twenty staff either active in river ice response and mitigation, or with enough experience to support these activities. By the end of 2006, eight active staffers remained and only one is entirely funded by river ice research. Given the aging of the river ice community, we suggest that active succession planning and knowledge transfer begin now to assure a robust and experienced future river ice community. This paper proposes that the Committee on River Ice Processes and the Environment form the nucleus of a cooperative effort in succession planning and knowledge transfer to support ice jam response and mitigation.

1. Introduction

River ice jams pose a threat to public safety, infrastructure, and the environment due to flooding, ice impacts, and secondary impacts such as scour and resuspension of contaminated sediments. But ice jams are also a natural process essential to ecosystem functioning, so ice mitigation measures must be carefully balanced to avoid unintended consequences to ecosystems. While understanding of ice engineering processes has improved over the past decades (Morse and Hicks 2005), knowledge of the important ice processes related to ecosystem function have only slowly emerged as a topic for research since the Workshop on Environmental Aspects of River Ice (Prowse 1993). This is despite a rapid increase in the design and construction of channel stabilization, ecosystem restoration, and ice mitigation structures in ice-affected rivers. The potential for unexpected results associated with these investments is high.

The design and operation of ice jam mitigation measures has depended on some degree of predictability in ice conditions and stationarity of ice records. This assumption is particularly important for ice events because records are sparse in comparison to open-water flood events. Ice conditions drive the evaluation and selection of techniques for both emergency and long-term ice mitigation, and methods and design approaches to mitigate freezeup ice jams are often quite different than for breakup ice jams. However, climate change has resulted in changes in the formation mechanisms and timing of ice events over the course of the past several years (Ginzburg and Soldatova 1997, Magnuson et al 2000, Beltaos and Prowse 2001, Prowse and Bonsal 2004). Some locations with long records of breakup jams are now experiencing freezeup jams as well (e.g., Vuyovich and White 2006). These changes suggest that risk and uncertainty associated with ice jam response and mitigation are increasing in response to climate change, despite increases in understanding of ice processes.

These potential surprises and increasing uncertainties are arising at a time when fewer trained specialists are available to support design and emergency response in ice-affected rivers. For example, in 1990, the US Army Corps of Engineers' (USACEs) Cold Regions Research and Engineering Laboratory (CRREL) had twenty staff either active in river ice response and mitigation, or with enough experience to support these activities. By the end of 2006, eight active staffers remained; the others had either retired or moved on to other research areas with greater funding resources. Of the eight active staffers, only one was entirely funded by river ice research.

By virtue of his long-term experience, Dr. Spyros Beltaos is often asked by public and private agencies to participate in Canadian ice jam control and remediation engineering projects and activities. The response is affirmative whenever such requests can be accommodated without serious impact on prior commitments and objectives. This type of involvement does not always generate new scientific knowledge but helps apply current knowledge of river ice processes to real-life problems in instances where the necessary expertise cannot be readily found (e.g. Beltaos et al. 2007a, b). Two relevant points are evinced by this situation: (a) there is a shortage of river ice specialists among Canadian engineers and consultants; and (b) there is little prospect for succession within Environment Canada as Dr. Beltaos is the only staff member who remains active in problems pertaining to ice jam response and mitigation.

The loss of capabilities in ice engineering through retirement and transition of skilled technical staff to other research areas is compounded by the aging of the international ice community. As an example, the four authors represent a total of 208 years with 85 years of ice-related experience, and are nearing or already eligible for retirement. We do not see a critical mass of younger technical staff ready to take over as we retire.

Benefits in the form of knowledge and technology advances resulting from the exchange of ideas between ice researchers cannot be underestimated. The international community of engineers and scientists involved with river ice hydraulics, exemplified by those participating in the activities of the Committee on River Ice Processes and the Environment, is relatively small and collegial. Building on their many years of experience and close ties, we believe that individual researchers must take the initiative to deepen the interaction between government agencies, universities, state and local agencies, and the private sector. The desired outcome will be a focus on knowledge transfer and capacity building to ensure a thriving ice engineering community equipped to meet public safety and environmental challenges now and in the future.

We suggest that the ice engineering community take an active role to assure a robust and experienced future river ice community as well as outreach efforts to stakeholders affected by ice impacts. This paper proposes that participants in the Committee on River Ice Processes and the Environment form the nucleus of a cooperative effort in succession planning and knowledge transfer to support ice jam response and mitigation. Four potential partners in this effort are discussed below, together with suggestions for future interaction.

2. US Army Corps of Engineers

CRREL, a laboratory of the USACE Engineer Research and Development Center (ERDC), has provided capability in the area of ice engineering area since the 1960's through its technical staff and with the aid of specialized facilities in the Ice Engineering Research Facility, built in 1976. CRREL conducts research and development activities both for the USACE (as direct and reimbursable studies) and for other federal agencies, state and local agencies, and the private sector. Current USACE research carried out by CRREL and its associates is concentrated on the knowledge and technology gaps associated with impacts to USACE projects and water resources management. More than half of US inland waterways navigation and about a third of navigation structures are located in ice-affected rivers (Tuthill 2002). Ice impacts to USACE projects include structural damage, reduced conveyance that results in flooding, ice blockage that results in delays to navigation, interruptions to hydropower production, intake blockage or day-lighting, and geomorphological or environmental effects.

CRREL has a long history of R&D that has successfully addressed persistent ice problems at locks and riverine structures such as lock and dam components, ice control structures, and ice booms (USACE 2006). CRREL has also contributed to numerical modeling capabilities for river ice hydraulics such as the widely-used HEC-2 model and its successors UNET, HEC-RAS, and Geo-RAS (e.g., Calkins et al 1982, USACE 1996, Tuthill et al 1998, USACE 2002a, b). CRREL has also developed specialized models such as the Discrete Element Model (e.g, Hopkins and Daly 2003, see http://www.crrel.usace.army.mil/sid/hopkins_files/Riverice/river_ice.htm) and supported the development of other specialized models such as DynaRICE (e.g., Liu and Shen 2000). Technology transfer has also been actively fostered by the Ice Jam Clearinghouse

(http://www.crrel.usace.army.mil/icejams/), which is supported by the USACE Civil Emergency Management Branch, and through active publication by the CRREL Ice Engineering Group (e.g., http://www.crrel.usace.army.mil/library/cat_riverlakeice.html, http://144.3.144.33/tectran/ieieb.htm).

CRREL research activities are continuing in the areas of ice forces on structures, ice hydraulic modeling, navigation impacts, and application of risk and uncertainty to ice engineering. Current and future research is also directed at knowledge gaps in ice jam prediction on both a site-specific and large spatial area basis; probabilistic approaches incorporating risk and uncertainty, including a method to estimate the joint probability of ice thickness and ice strength; responses to climate impacts; ice-related scour, sediment transport under ice, and ice impacts on geomorphology and habitat; the application of bioengineering methods in ice-affected rivers; and coastal shoreline protection design for cold regions (White and Davis 2006).

CRREL researchers have been active in the national ice engineering community through sponsorship of, and collaboration on, university research and innovative projects for other government agencies (e.g., Environmental Protection Agency, Department of Transportation). CRREL and the National Weather Service have been joining in training and capacity building activities to support effective ice jam emergency management. Internationally, CRREL researchers have long participated in conferences and workshops, to share knowledge about ice engineering issues. As an agency, CRREL has supported knowledge exchange through sabbaticals at international research institutions (e.g., Norway, Sweden) and by sponsoring foreign sabbaticals at CRREL (e.g., Japan, Czechoslovakia, Finland).

3. US National Weather Service: Weather Forecast Offices

The National Weather Service (NWS) is the agency charged with the issuance of flood/flash flood watches and warnings in the protection of lives and property (Organic Act of 1890, 26 USC 653-655). As such, the NWS Weather Forecast Offices (WFOs) have a 'front line' role with ice jam monitoring and response. Agency forecasters and hydrologists continuously monitor river conditions for the formation and breakup of ice and any associated flooding or flood potential. To accomplish this feat, the incorporation of several resources is necessary.

To identify, understand and monitor ice development and movement, WFOs work closely with other federal and state agencies. Information from gauges maintained through the winter by the US Geological Survey (USGS) is invaluable; however the gauges are sparsely distributed, can freeze up, be damaged with ice movement or vandalized. High resolution satellite imagery is becoming more readily available, for example Moderate Resolution Imaging Spectroradiometer (MODIS) images from the NASA Short-term Prediction Research and Transition Center (SPoRT). With the application of color enhancement, these images can indicate where river ice exists and movement of the ice, however updates are infrequent. The most critical tool is river observers; public and private individuals near the rivers that can provide a description of current conditions.

Through various fora, NWS forecasters and hydrologists receive training on river ice, ice processes, jam processes, and ice modeling, from agencies and institutions that study river ice, such as CRREL and the University of Alberta. Since 1994, the NWS has bi-annually convened a

Cold Regions Hydrology Workshop providing a forum of sharing and education for the agency's offices that are in areas that have snow or ice that turns into river water; CRREL and the University of Alberta have both made presentations at these conferences. Additionally, there are regional conferences and agency courses that provide river ice training. This information is further distributed to emergency managers and other river observers through local training events.

For the conterminous US, Montana leads in both the number of reported ice events and the number of ice jam deaths (CRREL Ice Jam Clearinghouse). Ice events have been reported on more than 160 different rivers and streams in nearly 200 different locations. Because of the diversity in topography and climate, ice events have been reported during all but a few months of the year. The four WFOs in Montana have taken a very proactive role in the public education of river ice by applying the knowledge and techniques gained from the research community to provide training to river observers across the state. Numerous local training events have been held since 1990 with many addressing the needs of the state's Disaster and Emergency Services Coordinators.

In 2006, the Great Falls Weather Forecast Office (WFO) dedicated its biannual Montana Hydrology Conference to the discussion of river ice and ice jams. An Ice Observer Handbook was created to assist in the identification of various ice and jam types. The conference was attended by representatives of 14 different offices of 3 Montana state departments, 13 different offices of 6 federal agencies, 6 county offices, 5 private firms/consultants and a high school. In 2007, the state WFOs sponsored Montana's first Ice Jam Awareness Day. A web site was created that provides an overview of ice events in Montana along with information on river ice and river ice processes (http://www.wrh.noaa.gov/tfx/hydro/MRIAD2007/mriadmain.php?wfo=tfx). A web-access database has been created on which the river observers record their observations and reports of the observations can be generated and reviewed by the WFOs (http://www.wrh.noaa.gov/tfx/icejam/icejam.php?state=MT).

Another example of NWS interagency and international sharing of data to monitor the rivers is the International Joint Commission (IJC) of Environment Canada and the National Weather Service for the Saint John River Basin. This commission was originally set to monitor water quality in the Saint John River. The commission and its stakeholders (e.g. the USGS, the NWS Northeast River Forecast Center, WFOs Caribou and Grey, Maine, New Brunswick Power) continue to meet annually and discussions have expanded to include other relative topics such cross-border sharing of warnings, forecasts and ice conditions as well as data transfer between agencies/governments.

4. Canadian Governmental Agencies: Environment Canada National Water Research Institute

Federal research activities that are relevant to ice jam response and mitigation have been conducted since 1979 at Environment Canada's National Water Research Institute (NWRI), which is based in Burlington, Ontario. Initially, this research was largely motivated by the need to provide expert input to engineering work being undertaken under the National Flood Damage Reduction Program (1970s to 1990s). Comprehensive field programs on the occurrence and

severity of ice breakup and jamming were conducted in SW Ontario (Thames and Grand Rivers) and in New Brunswick (Restigouche and Saint John Rivers) in collaboration with the New Brunswick Department of the Environment (e.g. Beltaos 1995, 1997, 2000, 2001). During about the same time frame, Environment Canada's National Hydrology Research Institute (NHRI), initially based in Ottawa and (after 1985) in Saskatoon, carried out similar research on the Mackenzie and Liard Rivers (e.g. Prowse 1986, Marsh and Prowse 1987).

NHRI staff were also involved in studies of the hydrometeorological conditions controlling ice-jam flooding of the Peace-Athabasca Delta, under the auspices of the Northern River Basins Study and the Peace-Athabasca Delta Technical Studies. (e.g. Prowse et al. 1996, Prowse and Conly 1998). Concern over the long-term ecological maintenance and sustainability of the Peace Athabasca Delta, one of the world's biologically richest freshwater deltas, was the main motivation for these studies.

The conclusion of the Flood Damage Reduction Program in the 1990s resulted in a shift of focus for river ice research to the then emerging issue of climate change. An administrative reorganization in 1997 rendered the National Hydrology Research Institute a branch of NWRI. Since then, ice-jam related research has been carried out as part of the Climate Impacts on Hydrology and Aquatic Ecosystems" Project (Dr. Terry Prowse, Chief) of the enhanced NWRI. This Project became closely affiliated with W-CIRC (Water and Climate Impacts Research Centre, also led by Dr. Prowse), which was established in 2002 in the Department of Geography, University of Victoria, under an agreement between the university and Environment Canada. Since 1997, numerous ice-jam related studies have been completed or are in progress [hydro-climatic aspects of ice-bridge interactions, climate impacts on ice-jam flooding of the Peace-Athabasca Delta, occurrence of mid-winter breakup under a warmer climate, ice effects on the annual peak river levels in the Mackenzie basin, hydroclimatic controls on the occurrence of extreme hydrological events in the Mackenzie Delta (e.g. Beltaos et al. 2006a,b,c; Prowse and Bonsal 2004, de Rham et al. 2006)]. Ongoing collaboration with the New Brunswick Flow Forecasting Centre aims to develop a capability for real-time prediction of ice jam water levels and flood risk assessment through use of ice jam models combined with GIS floodplain information.

5. Academic Institutions: University of Alberta

The University of Alberta has a long history of river ice research, most notably by the late Dr. R (Larry) Gerard, who was a professor in the Department of Civil Engineering at the University from 1977 until 1991. Dr. Gerard conducted seminal research on river ice jam formation and release processes, and well as research into ice jam flood forecasting. Since 1992, the second author has continued this research focus, developing a comprehensive river ice research program involving experimental, numerical, and field research studies. Formative research has been conducted in the lab: investigating ice jam consolidation processes (Healy and Hicks 2006, 2007) and ice floe hydrodynamics (Dow et al. 2007); and in the field, obtaining comprehensive scientific observations of ice jam formation and release events (Kowalczyk and Hicks, 2007, She et al. 2007), Considerable efforts have been focused on numerical model development, particularly for river ice cover formation processes (Andrishak and Hicks 2005) and ice jam release event modeling (She and Hicks, 2006) enhancing the capabilities of the University of

Alberta's public domain models: River1D and River2D (www.river2d.ca). New research methodologies employing Neuro Fuzzy Logic modeling have provided groundbreaking contributions to ice jam flood forecasting, including the first successful long lead time flood forecasting models (Mahabir et al. 2006), and forecasting model transfer between basins (Mahabir et al., 2007).

Collaborative research with the Canada Centre for Remote Sensing (Dr. Joost van der Sanden) has led to the advancement of remote sensing techniques for river ice characterization (Pelletier et al. 2005) using satellite synthetic aperture radar, and this research continues in collaboration with Dr. Monique Bernier at INRS-ETE (Gherboudj et al. 2007) and C-CORE. Additional collaborations with Dr. Brian Morse of Université Laval are directed towards the development of a unified river ice breakup model. New collaborations with Dr. Lance Lesack of Simon Fraser University and Dr. Phil Marsh of the National Hydrology Research Institute, will explore the effects of climate change on the nutrient fluxes and hydrology in the Mackenzie Delta during river breakup.

Public education is facilitated through the University of Alberta's river ice engineering web site (www.riverice.ca), providing introductory lecture material to educators (www.riverice.ualberta.ca/lecture_material.html). These electronic lectures have been requested for use by professors at the Universities of New Brunswick, McGill, Laval, Ottawa, Manitoba, Windsor, Memorial (Newfoundland), INRS-ETE (Quebec), and Alaska. Educational lectures have been also been requested by BC Hydro, Glacier Power, Alberta Environment, Indian and Northern Affairs Canada, and the US National Weather Service. The University of Alberta's river ice engineering web site also provides an electronic library of river ice literature to University of Alberta students, researchers and collaborators. The web site for the Committee on River Ice Processes and the Environment (www.cripe.ca) has also been developed and maintained by the University of Alberta river ice research group, who have also converted the entire library of CRIPE workshop proceeding to electronic format (http://www.cripe.ca/workshop_proceedings/publications_proceedings_index.html).

Graduates of the Masters and PhD programs in river ice engineering at the University of Alberta, as well as those from similar programs at Université Laval and the University of Manitoba, represent the next generation of ice experts. Some of these graduates have already made significant contributions in industrial settings (e.g. in hydropower companies like BC Hydro, Manitoba Hydro, and Quebec Hydro), in consulting, and in government settings (e.g. Alberta Environment and Quebec Environment). For example, all four of the engineers in Alberta Environment's river ice engineering team responsible for ice jam flood forecasting in Alberta, including the Team Leader, are graduates of the river ice engineering graduate program at the University of Alberta. However, unless more universities in Canada develop river ice research and training programs, and more specialized employment opportunities arise, the number of ice experts in Canada will likely decrease in the future.

6. Potential Interaction Supporting Succession Planning

In Canada, ice jam response and mitigation is typically within the mandate of provincial emergency measures organizations, or of provincial departments of water

resources/environment. It is the exception (as in Alberta), rather than the rule, to find in these organizations engineers and managers who have more than rudimentary training on river ice science and engineering. A similar situation exists in the US, where state and local agencies bear the brunt of ice jam response, with technical support provided by USACE and NWS.

Ice engineering researchers have benefited tremendously through their partnerships with the international community via the IAHR Symposia on Ice (held every other year) and the Canadian River Ice Workshops (held every other year). Universities have played a strong role in the ice engineering community from the start, both in basic and applied research and in collaboration with government agencies. If we are to evolve from our current aging population to a thriving ice engineering community equipped to meet public safety and environmental challenges now and in the future, we must begin active succession planning that includes an expansion of the current informal knowledge transfer across agency, academic, and international boundaries, and includes all levels of government agencies, from federal to local.

Successful planning and implementation will require that we step outside our technical specialties and take advantage of recent models for decentralized organizations which rely on peer relationships and networks or connections between individuals (e.g., Gladwell 2000, Collins 2005, Brafman and Beckstrom 2006, Tapscot and Williams 2006). We should also tap into the ice engineering community's skill at teaching and develop distance learning mechanisms to support knowledge transfer that builds on current web sites such as the Ice Jam Clearinghouse, the Montana Ice Jam Database (http://www.wrh.noaa.gov/tfx/icejam/icejam.php?state=MT) and Ice Jam Awareness (http://www.wrh.noaa.gov/tfx/hydro/MRIAD2007/mriadmain.php?wfo=tfx), and the University of Alberta's river ice web site (www.riverice.ca). Our approach should also acknowledge advances in cognitive learning based on Bloom's taxonomy (Bloom et al 1956, Anderson and Krathwohl 2001).

The authors would like to form a group to increase interaction and foster succession planning and knowledge transfer, and suggest that this CRIPE workshop provides an ideal forum for brainstorming to develop a strategy and an implementation plan. Several suggestions are identified below:

- Expand and formalize relationships. A model could be the connections that have developed over the years between USACE staff and members of other US government agencies through their joint participation in ice jam emergency response.
- Transfer technology and information. Numerous opportunities exist in this area.
  - The CRREL Ice Jam Database represents a merging of information by USACE, NWS, and USGS used in emergency response and engineering design. It has recently (June 2007) transitioned from a text-based database to an Oracle database. We will explore a partnership that allows NWS to enter event information directly via secure network connections. This will speed the transfer of information in emergency situations and ensure a critical mass of trained staff to support emergency management. We can improve reporting for transnational rivers such as the St. John River and Souris River to assist both US and Canadian agencies.
  - The University of Alberta's public domain models River1D and River2D (www.river2d.ca) offer the means for expanded research into the development, validation

and application of ice process models. However, integration of these new technologies into more mainstream models such as the HEC-RAS model, would likely have a much more widespread impact. As a first step, we will explore a partnership that will see the ice cover development process model components developed for River1D implemented in HEC-RAS program. A similar undertaking earlier, in which the steady ice jam profile model: ICEJAM (Flato and Gerard, 1986) was implemented in the HEC-RAS model suite, was extremely successful in increasing the use of this approach for ice jam profile computations.

- Formal training. The ultimate objective is formalized instruction on river ice and ice jam processes at most Canadian and some US Universities, potentially with distance learning methods for some subjects. For many years, Dr. C. Alan Wortley provided ice-related continuing education courses at the University of Wisconsin, Madison. This type of model could be considered, possibly based at the University of Alberta. CRREL's Dr. Steve Daly has included ice jam modeling as part of a course on Arctic Hydrology and Hydraulics at the University of Alaska. This course is taught partially using distance learning. CRREL's Dr. Kate White has provided training to NWS staffers via its Cooperative Program for Operational Meteorology, Training, and Training (COMET) courses since the late 1990's as a short segment within a week-long course on flash floods.

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